UNITED STATES PATENT APPLICATION

FOR

CRITICAL DIMENSION MEASUREMENT BY DIFFRATION

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Attorney Docket No.: 42P16017

"Express Mail" mailing label number: EV 336 584 179 US
Date of Deposit: September 12, 2003
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CRITICAL DIMENSION MEASUREMENT BY DIFFRATION

FIELD OF THE INVENTION

[0001] This invention relates to measuring a critical dimension in microelectronic devices, and more particularly to use of diffraction patterns to measure the critical dimension in a microelectronic device.

BACKGROUND OF THE INVENTION

[0002] Measurement or confirmation of feature size or "critical dimension" ("CD") confirms accuracy and tolerances at many stages of microelectronic device manufacture. For example, CD may be measured upon production of a partially transmissive mask before utilizing said mask to produce layered devices. Subsequent to utilizing a mask to pattern one or more layers of a microelectronic device, CD may again be measured to confirm geometric accuracy and tolerances.

[0003] As device sizes continue to shrink, accurately measuring the size of features becomes increasingly difficult. Current methods to provide accurate and precise measurements of CD of small features inexpensively are unsatisfactory. For example, current techniques such as those utilizing scanning electron microscopy or optical metrology may lack the requisite precision due to substrate charging, or may be limited physically by the Raleigh resolution limit associated with light microscopy. In measuring CD of a mask, both current optical and SEM metrology tools lack the ability to measure CD smaller than about 250 nm, due to diffraction and substrate charging. In measuring CD of features on a wafer, current tools lack the ability to measure CD smaller than about 90 nm.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] The present invention is illustrated by way of example and is not limited in the figures of the accompanying drawings, in which like references indicate similar elements. Features shown in the drawings are not intended to be drawn to scale, nor are they intended to be shown in precise positional relationship.

[0005] Figure 1 depicts a top view of various aspects of a substrate with reflective or transmissive features, the geometry of which may be measured in accordance with one embodiment of the present invention.

[0006] Figure 2 depicts a close-up top view of various aspects of a substrate with reflective or transmissive features, the geometry of which may be measured in accordance with one embodiment of the present invention.

[0007] Figure 3A depicts a cross-sectional side view of various aspects of one embodiment of the present invention wherein radiation passed through a transmissive feature is detected on the opposite side of the feature from the radiation source.

[0008] Figure 3B depicts a cross-sectional side view of various aspects of one embodiment of the present invention wherein radiation reflected off of a reflective feature is detected on the same side of the feature as the radiation source.

[0009] Figure 4 depicts a representation of a diffraction pattern and associated relationships conventional to diffraction analysis.

DETAILED DESCRIPTION

[0010] In the following detailed description of embodiments of the invention, reference is made to the accompanying drawings in which like references indicate similar elements. The illustrative embodiments described herein are disclosed in sufficient detail to enable those skilled in the art to practice the invention. The following detailed description is therefore not to be taken in a limiting sense, and the scope of the invention is defined only by the appended claims.

[0011] Referring to Figure 1, an example substrate (100) is depicted with a series of example features (102, 104, 106, 108, 110). In the case of a mask structure such as those utilized for semiconductor patterning, the features (102, 104, 106, 108, 110) may be translucent to various types of radiation, while the surrounding substrate (100) material is configured to be substantially opaque to various types of radiation. In the case of a semiconductor structure, the features (102, 104, 106, 108, 110) may be layers formed, for example, to define gates, while the substrate (100) may comprise a semiconducting material such as silicon. In such semiconductor structures, the features (102, 104, 106, 108, 110) may be reflective of various types of radiation. The CDs of various other arrangements of features on substrates may also be measured.

[0012] In the illustrated embodiment, the feature size to be measured is be the widths "w" (112, 114, 116, 118, 120) of the features (102, 104, 106, 108, 110), although other dimensions may be measured as the CD in other embodiments. The features (102, 104, 106, 108, 110) may be spaced apart, with spacings "d" (122, 124, 126, 128) between the features (102, 104, 106, 108, 110). There is a spacing "d" (122) between features (102) and (104), for example. Further, there may be pitches "p" (130, 132, 134, 136), which are the sum of a spacing "d" (122, 124, 126, or 128) and a width "w" (102, 104, 106, or 108). For example, the pitch "p" (130) may be equal to the sum of width "w" (112) of feature (102) plus the spacing "d" (122) between feature (102) and feature (104). In an embodiment, the pitches "p" (130, 132, 134, 136) may be known.

[0013] Referring to Figure 2, this measurement task is illustrated with a closer view of the substrate (100) and two adjacent features (102, 104). The pitch "p" (130) (the sum of the distance "d" (122) between the two features (102, 104) and the width "w" (112) of feature (102)) is known in this embodiment. The feature size to be measured in this embodiment is the width "w" (112) of the feature (102).

[0014] Referring to Figure 3A, an embodiment of a system (300) to measure CD or feature size is illustrated. This embodiment of the system (300) utilizes diffraction pattern matching to measure the CD. Figure 3A is a side view showing a substrate (100) and feature (102), such as those depicted in Figures 1 and 2, in cross section. A radiation source (302), such as a laser, x-ray source, or high-energy electron source, may be utilized to irradiate the substrate (100) and feature (102), with the radiation (304) striking the substrate at an angle of incidence (310). In the embodiment of the system (300) illustrated in Figure 3A, the substrate (100) is substantially opaque to the incoming radiation (304) at the angle of incidence (310) while the feature (102) allows passthrough of such radiation (304) to produce a diffraction pattern (308). This diffraction pattern (308) strikes a detector (306), which detects the diffraction pattern (308).

[0015] In an embodiment, the substrate (100) may be held in place by a stage (not shown) which is capable of highly-accurate positioning of the substrate (100) relative to the source (302) and detector (306). Precision stages for focusing in on features are known, and are available, for example, for SEM, e-beam exposure tools, wafer stepper/scanner stages, and interferometer applications by suppliers such as Hewlett Packard Company. Detectors (306) for detecting diffraction patterns (308), including the positions of diffraction pattern maxima and minima, are well known in the art. For example, with x-ray radiation, diffraction tools such as the XDS2000 X-ray Diffractometer from Scintag Corporation comprise high-resolution maxima and minima detectors. Should x-ray or high-energy electron be utilized as the irradiation modality, a vacuum enclosure (not shown) around the radiation source, stage, and detector may be used in some embodiments. In other

embodiments, laser light may be used as the radiation (304), and no vacuum enclosure may be used. In one embodiment, a laser source with a wavelength "λ" longer or larger than "w," for example, a helium-neon laser having radiation (304) wavelength of about 633 nanometers, may be utilized as a source (302), and a charge-coupled device ("CCD chip") may be utilized as a detector (306) of the diffraction pattern (308).

[0016] In an embodiment, the detector (306) may be connected to a computer system (not shown) to capture and store the diffraction pattern (308), including the diffraction pattern maxima and minima, for later use.

[0017] Referring to Figure 3B, an embodiment of an alternate system (350) to measure CD is depicted. The alternate system (350) illustrated in Figure 3B is similar to the system (300) illustrate in Figure 3A. However, in Figure 3B the feature (102) reflects the radiation (304) back toward the source (302). Thus, a diffraction pattern (308) is created on the same side of the substrate (100) as the source (302). The detector (306) is on the same side of the substrate (100) as the source (302) to detect the diffraction pattern (308) that is formed by reflection of the radiation (304) by the feature (102). The detector (306) may be connected to a computer system (not shown) to capture and store the diffraction pattern (308), including the diffraction pattern maxima and minima, for later use.

[0018] Referring to Figure 4, one embodiment of a graphical depiction (400), or "graph," of the diffraction pattern (308) detected by the detector (306) is illustrated. Such a graph (400) may be generated, for example, by a computer system to which the detector (306) is connected. The graph (400) of Figure 4 shows a diffraction pattern intensity plot (402) as well as an envelope plot (404) that follows along the maximas (406) of the diffraction pattern intensity plot (402).

[0019] The graph (400) of the diffraction pattern is related to the size (112) of the feature (102) to be measured. In an example based on Figure 2, the maximas (406) and minimas (408) of the graph (400) are dependent upon the spacing between features (122) and the feature size (112) of the

feature (102). As illustrated in Figure 3, the diffraction pattern intensity plot (402), "I/I_o," is given by Equations 1 through 3:

(Eqn. 1): $I/I_o = ((\mathrm{Sin}(\alpha))/\alpha)^2 * \mathrm{Cos}^2(\gamma)$

where:

(Eqn. 2): $\alpha = 0.5 * k * w * \mathrm{Sin}(\theta)$

(Eqn. 3): $\gamma = 0.5 * k * d * \mathrm{Sin}(\theta)$

w = the feature size (112)

d = the spacing between features (122)

θ = the angle of incidence (310)

k = the number of waves per unit length, equal to $2\pi/\lambda$, and

λ = the wavelength of incident light from the source (302)

The angle of incidence (310) may be a selected, known value. As described above, pitch may be a known value equal to the sum of "d" and "w." Thus, the spacing "d" (122) may be given in Equation 4 as:

(Eqn. 4): $d = p - w$

Given this information, Equation 1 therefore sets out the relationship of the diffraction pattern intensity "I/I_o" (402) to the feature size "w" (112).

[0020] The envelope plot (404) is also related to feature size and may also be used to aid in determining the feature size "w" (112). The envelope plot (404), is related to the feature size because the envelope plot is defined by $(\mathrm{Sin}(\alpha))/\alpha)^2$, where Equation 2 above defines α.

[0021] Thus, for a given pitch "p" (130), different feature (102) widths (112) will result in different diffraction patterns (308), and different plots (402, 404) of the diffraction patterns (308), as shown by Equations 1-4.

[0022] In one embodiment, one or more of these relationships between the diffraction pattern (308) and feature size (112) may be used to quickly determine the feature size (112) of the feature (102) through a comparison process. In an embodiment, aspects of the diffraction pattern (308) may be used as a feature size identifier, or "fingerprint," of the CD being measured. In various embodiments, the feature size identifier, or "fingerprint," may be the diffraction pattern intensity plot (402), the envelope plot (404), both plots (402, 404), locations of the maximas (406) of the diffraction pattern intensity plot (402), locations of the minimas (408) of the diffraction pattern intensity plot (402), or other aspects of the diffraction pattern (308) or combinations of aspects of the diffraction pattern (308).

[0023] In an embodiment, a computer system has a stored library of such "fingerprints," each of which is associated with a particular known pitch "p." The computer may receive the detected diffraction pattern (308) from the detector (306). The "fingerprint" of the feature (102) being measured may then be compared with the stored library of "fingerprints" to find a match and thereby determine the feature size (112) of the feature (102) being measured. Since the pitch "p" (130) of the feature (102) being measured is known, the detected feature size identifier may be compared with stored feature size identifiers with the same pitch "p" to determine the feature size in an embodiment. Pattern matching algorithms and software applicable to such a task are well known.

[0024] In summary, a detected diffraction pattern (308) for a feature (102) with a known pitch (130) may include a feature size identifier related to the size of the feature (102). This feature size identifier may be compared to a library of feature size identifiers that correspond to known feature sizes. Matching the feature size identifier to an identifier in the library may then identify the size of the feature (102) being measured.

[0025] In another embodiment, the feature size (112) may be calculated using the detected diffraction pattern intensity and the equations above. For example, "w" and "d" may be solved for by solving Equations 2 and 3 simultaneously (two variables defined by two equations), given a

known value of θ and selected values of α and γ. Other ways to calculate "w" and "d" from the detected diffraction pattern intensity and the equations above may also be used. For example, the magnitude of a detected feature size identifier, such as the intensity of a particular maxima (406) or minima (408) at a specific selected value of α and γ may be quantified by a computer or other device connected to the detector (306). This quantified intensity and the values for α and γ may be used in conjunction with the Equations above to calculate the feature size.

[0026] Thus, a novel CD measurement solution is disclosed. Although the invention is described herein with reference to specific embodiments, many modifications therein will readily occur to those of ordinary skill in the art. Accordingly, all such variations and modifications are included within the intended scope of the invention as defined by the following claims.